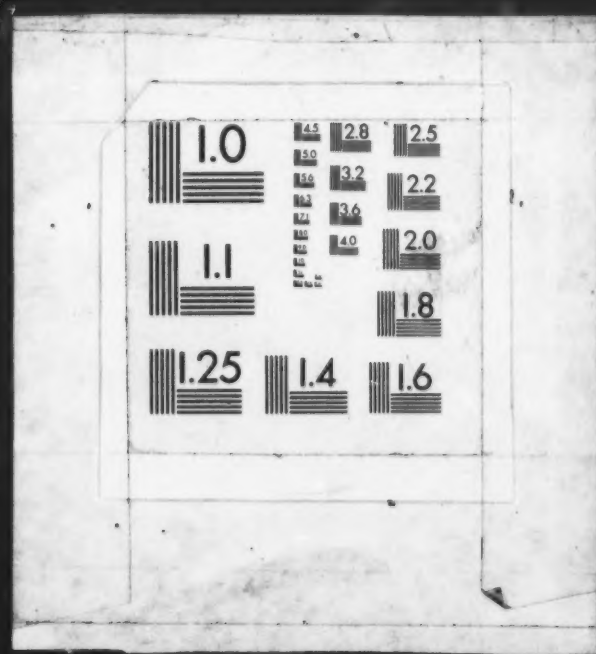


1 OF 1
PB87
147187



Pilot Plant Testing of Electrostatic
Fabric Filtration at Harrington Station

Southwestern Public Service Co., Amarillo, TX

Prepared for

Environmental Protection Agency
Research Triangle Park, NC

Jan 87



PB87-147187

EPA/600/D-87/036
January 1987

Pilot Plant Testing of Electrostatic
Fabric Filtration at Harrington Station

by

Richard Serrurier
Southwestern Public Service Company
Amarillo, Texas 79170

EPA Contract No.
68-02-2659

EPA Project Officer
Dale L. Harmon

Air and Energy Engineering Research Laboratory
Office of Research and Development
U.S. Environmental Protection Agency
Research Triangle Park, NC 27711

REPRODUCED BY
U.S. DEPARTMENT OF COMMERCE
NATIONAL TECHNICAL
INFORMATION SERVICE
SPRINGFIELD, VA. 22161

TECHNICAL REPORT DATA (Please read instructions on the reverse before completing)		
1. REPORT NO. EPA/600/D-87/036	2.	3. RECIPIENT'S ACCESSION NO. PB87 147187AS
4. TITLE AND SUBTITLE Pilot Plant Testing of Electrostatic Fabric Filtration at Harrington Station	5. REPORT DATE January 1987	
	6. PERFORMING ORGANIZATION CODE	
7. AUTHOR(S) Richard Serrurier	8. PERFORMING ORGANIZATION REPORT NO.	
9. PERFORMING ORGANIZATION NAME AND ADDRESS Southwestern Public Service Company Amarillo, Texas 79170	10. PROGRAM ELEMENT NO.	
	11. CONTRACT/GRANT NO. 68-02-2659	
12. SPONSORING AGENCY NAME AND ADDRESS EPA, Office of Research and Development Air and Energy Engineering Research Laboratory Research Triangle Park, NC 27711	13. TYPE OF REPORT AND PERIOD COVERED Published paper; 1/83-8/85	
	14. SPONSORING AGENCY CODE EPA/600/13	
15. SUPPLEMENTARY NOTES AEERL project officer is Dale L. Harmon, Mail Drop 61, 919/541-2429.		
16. ABSTRACT The paper gives results of pilot plant tests of electrostatic fabric filtration (ESFF) at Harrington Station, near Amarillo, Texas. In early 1983, the pilot baghouse at Harrington Station was modified to conduct a testing program for ESFF. The tests conducted there successfully demonstrated the ESFF concept on a commercial scale and confirmed the favorable effect of reduced filtration pressure drop previously observed in both laboratory and small scale tests. The unique woven-in electrode concept employed has been successfully demonstrated from both bag construction and operational standpoints.		
17. KEY WORDS AND DOCUMENT ANALYSIS		
a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Pollution	Pollution Control	13B 13A
Filtration	Stationary Sources	07D 21D
Electrostatics	Electrostatic Fabric	20C 21B
Fabrics	Filtration	11E 14G
Tetrafluoroethylene Resins	Woven-in Electrodes	11I
Utilities	Particulate	
18. DISTRIBUTION STATEMENT Release to Public	19. SECURITY CLASS (This Report) Unclassified	21. NO. OF PAGES 34
	20. SECURITY CLASS (This page) Unclassified	22. PRICE

NOTICE

This document has been reviewed in accordance with U.S. Environmental Protection Agency policy and approved for publication. Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

PILOT PLANT TESTING OF
ELECTROSTATIC FABRIC FILTRATION
AT HARRINGTON STATION

BY

RICHARD SERRURIER
SOUTHWESTERN PUBLIC SERVICE COMPANY
AMARILLO, TEXAS

ABSTRACT

In early 1983, the pilot baghouse at Harrington Station was modified to conduct a testing program for electrostatic fabric filtration (ESFF). The testing conducted at Harrington successfully demonstrated the ESFF concept on a commercial scale and confirmed the favorable effect of reduced filtration pressure drop previously observed in both laboratory and small scale testing. The unique woven-in electrode concept employed has been successfully demonstrated from both bag construction and operational standpoints.

This paper has been reviewed in accordance with the U.S. Environmental Protection Agency's peer and administrative review policies and approved for presentation and publication.

The work described in this paper was performed by Southwestern Public Service Company under contract to the U.S. Environmental Protection Agency, Contract 68-02-2659. EPA project officer was Dale L. Harmon.

INTRODUCTION

In 1977, the Environmental Protection Agency (EPA) executed a contract with Southwestern Public Service Company (SPS) to assess the performance of a large fabric filter system on a utility boiler burning low sulfur western coal. SPS's Harrington Station Unit 2, located northeast of Amarillo, Texas, was selected as the test site. One of the options of this contract provided for the installation of a pilot filter system for studies additional to the large scale work.

The pilot option was exercised and equipment was designed, purchased, and installed. Shakedown testing began October 23, 1979; however, numerous operating problems and mechanical flaws were encountered and it was May 5, 1980, before the pilot unit was declared operational. The pilot unit has been operated ever since for a variety of filtration test purposes. In early 1983, the pilot unit was modified to conduct an electrostatic fabric filtration (ESFF) testing program which is the subject of this presentation.

EQUIPMENT DESCRIPTION

The pilot unit is a Wheelabrator-Frye, Inc., Model 366, Series 11.5 RS Dustube Dust Collector. It has two six-bag compartments and initially was fitted with Criswell Style 442, 10 percent Teflon-coated fabric bags. The bags are 11.5 *in. in diameter and 366 in. in length untensioned. Cloth area per compartment is 549 ft² with a full complement of bags.

The unit is operated by a 480 V control panel and an instrumentation panel. The 480 V control panel houses the damper controls, hopper heater controls, cleaning cycle timers, fan start/stop controls, and bypass automatic controls. The instrumentation panel houses differential pressure (ΔP),

* Readers more familiar with metric units are asked to use the conversion factors at the end of this paper.

flow, and temperature monitoring devices for each compartment. Pressure drop for the respective bag compartments is measured from the inlet tube sheet to the clean gas side of the filter bags; it is measured and reported in inches of water.

The pilot unit is installed at the southeast corner of the east baghouse on Harrington's Unit 2; Unit 2 is a 360 MWe unit. The inlet flue gas to the pilot unit is pulled from the east inlet duct of the main baghouse and mixed with the hot preheater flue gas through a mixing valve to maintain temperature. A simplified flow schematic is shown in Figure I.

The pilot unit is set up for both shaker and reverse air cleaning modes. A variable speed shaker is used on the east compartment and constant speed on the west. During ESFF testing, reverse air cleaning was used for all test measurements.

COAL AND FLUE GAS CHARACTERISTICS

The coal burned at Harrington is a low-sulfur western coal from the Powder River Basin in the Gillette, Wyoming, area. The coal heating value ranges from 8600 to 8900 Btu/lb and is typically about 8800 Btu/lb. Ash content is usually between 4.9 and 5.0 percent. Sulfur content is typically 0.28 percent (wt) yielding a sulfur dioxide release value of 0.637 lb/MMBtu. A typical coal analysis (11-20-84) is summarized in Table I.

Flyash content of Harrington flue gas is in the range of 1 to 1.5 gr/acf. An analysis typical of flyash collected in the main baghouse is summarized in Table II.

Flue gas data for Harrington Unit 2 operation are summarized in Table III. Amarillo is at about 3600 ft in elevation and the average absolute pressure is 12.92 psia. Flue gas is supplied to the pilot baghouse via a

FIGURE I
ESFF PILOT PLANT FLOW SCHEMATIC

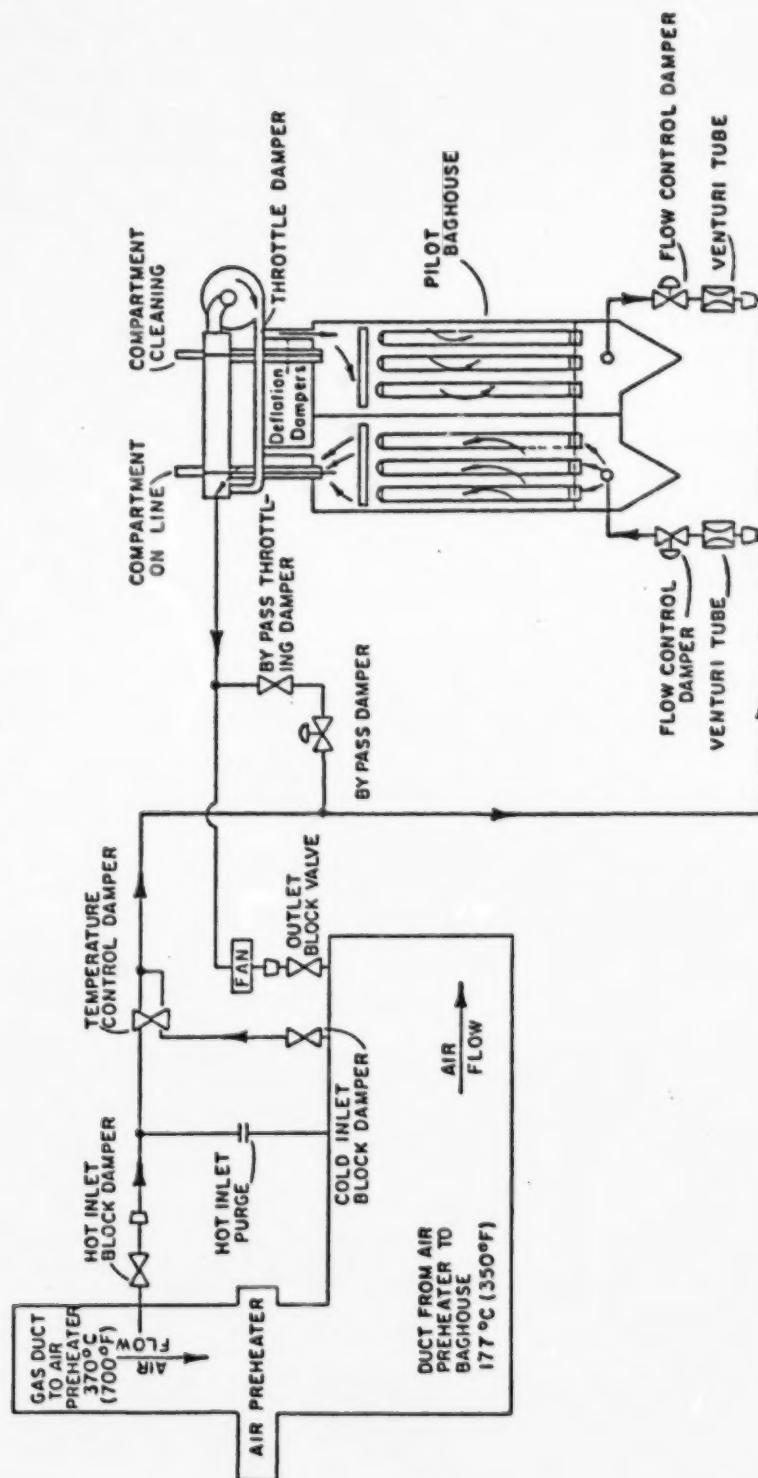


TABLE I
SOUTHWESTERN PUBLIC SERVICE COMPANY
HARRINGTON STATION
COAL ANALYSIS

Proximate Analysis

	<u>As Received</u>	<u>Dry Basis</u>
% Moisture	26.98	XXXXX
% Ash	4.94	6.77
% Volatile	31.15	42.66
% Fixed Carbon	<u>36.93</u> 100.00	<u>50.57</u> 100.00
Btu/lb	8,802	12,054
% Sulfur	0.28	0.39
MAF Btu/lb		12,929
% MAF Volatile		45.76
% MAF Fixed Carbon		54.24
Lb Sulfur Dioxide/MMBtu		0.65
% Air Dry Loss		10.79

Ultimate Analysis

	<u>As Received</u>	<u>Dry Basis</u>
% Moisture	26.98	XXXXX
% Carbon	50.81	69.58
% Hydrogen	3.62	4.96
% Nitrogen	0.69	0.94
% Chlorine	0.04	0.05
% Sulfur	0.28	0.39
% Ash	4.94	6.77
% Oxygen	<u>12.64</u> 100.00	<u>17.31</u> 100.00
Moist MM Free Btu/lb		9,298*
% Dry MM Free Volatile		45.38
% Dry MM Free Fixed Carbon		54.62
Lb Sulfur/MMBtu		0.33

* Based on as-received moisture

Sample analyzed 11-20-84

TABLE II

SOUTHWESTERN PUBLIC SERVICE COMPANY

HARRINGTON STATION

ASH ANALYSIS

SEPTEMBER 1984 - COMPOSITE

Chemical Analysis	Results	Spec * Class F/C
Silicon Dioxide (SiO ₂) %	30.10	
Aluminum Oxide (Al ₂ O ₃) %	19.90	
Iron Oxide (Fe ₂ O ₃) %	7.60	
Sum of SiO ₂ , Al ₂ O ₃ , Fe ₂ O ₃ % Min.	57.60	70/50
Calcium Oxide (CaO) %	30.80	
Magnesium Oxide (MgO) %	4.30	5.00 Max.
Sodium Oxide (Na ₂ O) %	0.80	
Potassium Oxide (K ₂ O) %	0.63	
Sulfur Trioxide (SO ₃) %	1.50	5.00 Max.
Moisture Content %	0.13	3.00 Max.
Loss on Ignition %	0.42	12/6 Max.
Available Alkalies (As Na ₂ O) %	1.20	1.50 Max.
Available Sodium (As Na ₂ O) %	0.96	
Available Potassium (As K ₂ O) %	0.34	

* ANSI/ASTM C618-80

TABLE III

ESTIMATED FLUE GAS CHARACTERISTICS

Coal Identity: Harrington 11/20/84

Ultimate Analysis, Wt%

% Carbon: 50.81

% Hydrogen: 3.62

% Nitrogen: 0.69

% Chlorine: 0.04

% Sulfur: 0.28

% Ash: 4.94

% Water: 26.98

% Other: 0.00

% Oxygen by Diff: 12.64

Higher Heating Value, Btu/lb: 8802 (As Received Basis)

Air Humidity, lb H₂O/lb Dry Air: 0.0075

% Combustible Loss: 0.10

Flyash Split, % Ash to Flyash: 80.00

O₂ Content of Flue Gas, % Wt: 4.000COMPUTED FLUE GAS COMPOSITION

<u>Comp</u>	<u>lb/100 lb</u>	<u>% Wt</u>	<u>Moles</u>	<u>% Mol</u>
CO ₂	185.824	20.340	4.222	13.477
H ₂ O	65.414	7.160	3.361	11.589
SO ₂	0.559	0.061	0.009	0.028
O ₂	36.543	4.000	1.142	3.645
N ₂	614.388	67.251	21.930	69.998
Other	10.807	1.183	0.395	1.259
NO _x	0.000	0.000	0.000	0.000
HCl	0.041	0.005	0.001	0.004
Total	913.577	100.000	31.060	100.000

PPM (Wt) SO₂: 612.402PPM (Vol) SO₂: 278.767Lb SO₂ Incident/MMBtu: 0.637

Flue Gas Molec. Wt: 29.160

ACFM Flue Gas/100 lb coal: 21485.259

Lb Coal Fed/MMBtu Released: 113.793

% Excess Air: 24.125

Grains Partic/ACFM Flue Gas: 1.320

Lb Comb. Air (Dry): 812.523

Lb Comb. Air (Wet): 818.617

slipstream from the east inlet duct of the main baghouse at a pressure of 10 to 15 in. H₂O below atmospheric.

ESFF BACKGROUND

The use of fabric filters to remove particles from gas streams is a well-established industrial practice. It is currently the most cost-effective particulate control device for many coal-fired electrical utilities.

Electrostatic fabric filtration (ESFF) consists of applying a nonionizing electrostatic field to the fabric filter media at the fabric/dirty gas interface. The residual and operating pressure drops are reduced with no apparent loss in collection efficiency. Previous laboratory and pilot-scale studies have consistently demonstrated this reduced pressure drop.

The original concept of ESFF was developed by Lamb and Costanza (1977) of Textile Research Institute (TRI). Continuing extramural research under the sponsorship of the U.S. Environmental Protection Agency (EPA) has encompassed:

- . Laboratory experiments at TRI and Research Triangle Institute (RTI) to develop a more basic understanding of the fundamental mechanisms of ESFF.
- . Pilot studies of pulse-jet and, to a much smaller degree, reverse-air ESFF applied to an industrial boiler at a DuPont facility in Waynesboro, Virginia.

In addition, the EPA has continued in-house research on ESFF at the laboratory and small pilot unit scale. As a logical extension of previous work, the application of ESFF to a full-scale electrical utility was undertaken.

THE ESFF PROGRAM

The objective of the ESFF program was to determine and to demonstrate the technical feasibility of the ESFF concept as applied to an operating utility boiler burning pulverized, low-sulfur western coal. There were several

developmental challenges, including the bag design, which had to be met in the process.

RTI was subcontracted by SPS to design and fabricate the ESFF hardware and to work with vendors in the development of an ESFF system. The successful implementation of this project then represents two first-time achievements:

- . The first application of ESFF to a commercial-scale fabric filter bag.
- . The first demonstration of a woven-in electrode fiberglass filtration fabric for ESFF on a commercial scale.

The development and production of the filter bags used for this experiment entailed considerable effort. The following summary presents the highlights of this successful project.

DEVELOPMENT OF A SUITABLE ELECTROSTATIC FABRIC FILTER BAG

There are three basic cleaning mechanisms used for fabric filters: reverse air, pulse jet, and shake/deflate. Prior to this project, the ESFF concept had been proved by EPA using a pulse-jet system and reverse-air cleaning at a somewhat smaller scale. The choice of cleaning method has important consequences for the design of the electrical hardware, the design of the filter bag, and the method of producing the electrostatic field at the fabric interface. Once the cleaning mode decision was made it was possible to proceed with other design considerations. Because a large number of commercial utility baghouses are reverse-air cleaned, it was decided to continue the scale-up development of the ESFF bag using reverse-air cleaning. Assuming that integral woven electrodes would be used, the decision to use reverse-air cleaning also avoided the probable difficulty of premature fabric failure because of abrasion between the woven-in electrodes and the fiberglass fabric.

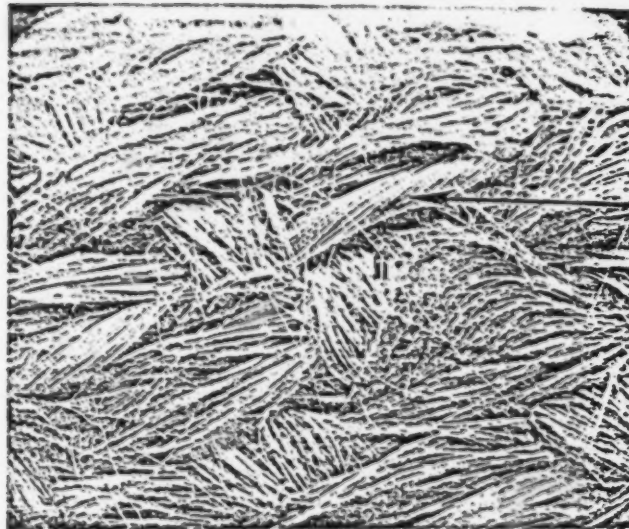
A reverse-air ESFF bag with integral electrodes had not been fabricated prior to this project, but this was now considered essential to demonstrate the applicability of ESFF on a commercial scale. Other conceivable configurations, including use of cylindrical rigid conducting cages located outside conventional bags, were considered. At SPS's suggestion, the woven electrode fabric was considered preferable since it would be much more easily adapted to commercial baghouses. Design and construction considerations for the woven electrode bag included that the bag should:

- . Use fabric woven on conventional looms.
- . Be sewn on conventional equipment.
- . Use nonconductive anticollapse rings.
- . Incorporate suitable electrical connectors and buses.
- . Be easily installed in the field.
- . Have an adequate service life.

After considering the various options available within project constraints, it was decided that J.P. Stevens 648 fiberglass fabric with integrally woven Bekaert VN-22/1x90 stainless steel electrodes would be used to make the reverse-air fabric filter bag. The electrodes would be located on 2 cm centers. Reasons for the choice of this fabric, electrode, and construction pattern included:

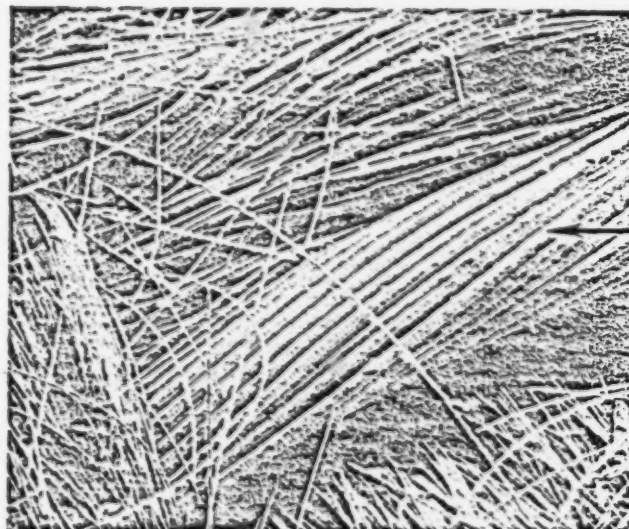
- . J.P. Stevens 648 fabric was (at the time) the only commercially available fiberglass filtration fabric that has texturized warp yarns. Weaving a metal electrode into a fiberglass fabric resulted in pinholes during early weaving test runs prior to this program. It was important to ensure that these pinholes, where penetration by particulates during filtration would occur, were minimized or eliminated. This was accomplished by "piggybacking" the stainless steel electrode with the texturized warp yarn. This also required an electrode small enough to fit into the same space in the loom (dent) as the texturized warp yarn.

FIGURE II
MAGNIFIED VIEW OF WOVEN
ELECTRODE FABRIC



a. Magnification = 15X

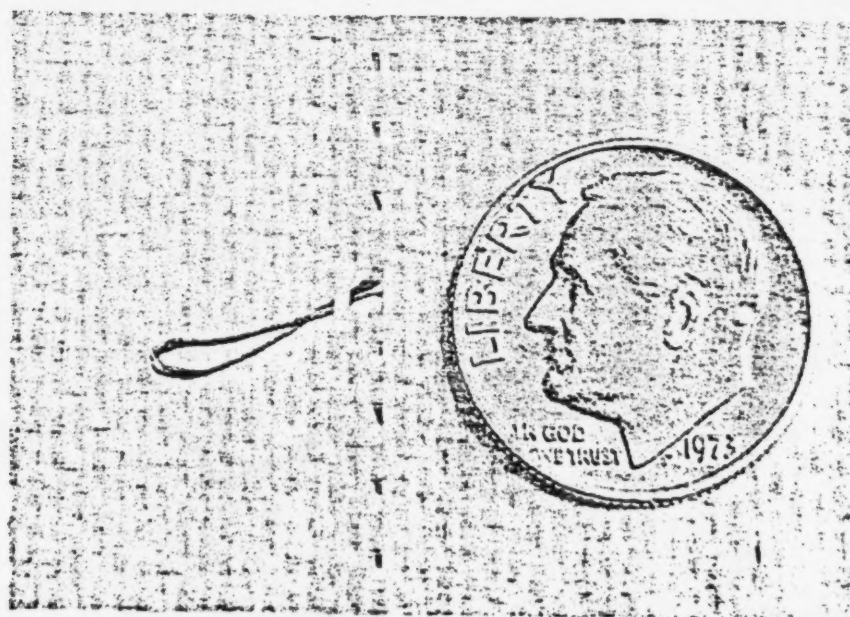
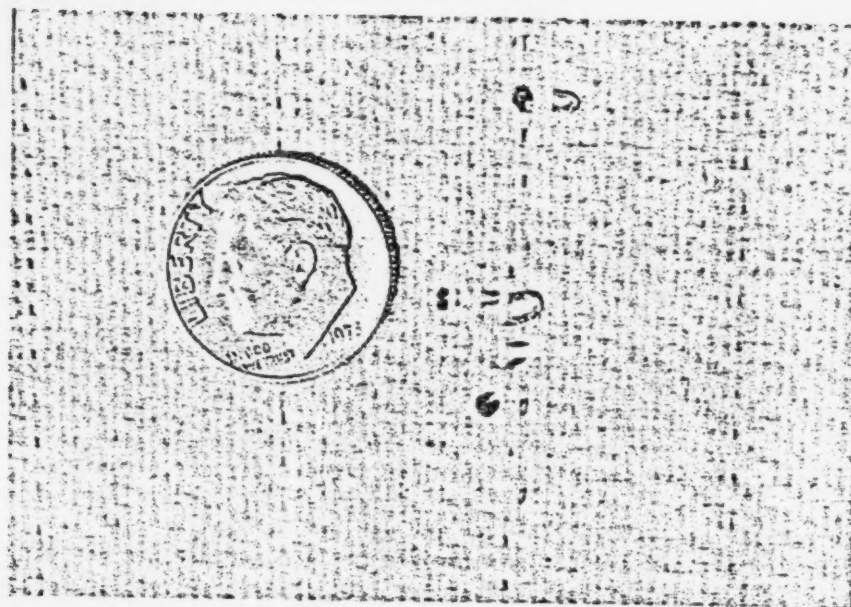
Stainless
steel
fiber



b. Magnification = 60X

Stainless
steel
fiber

FIGURE III
TYPICAL WEAVING DEFECTS IN WOVEN
ELECTRODE FABRIC



Reproduced from
best available copy.



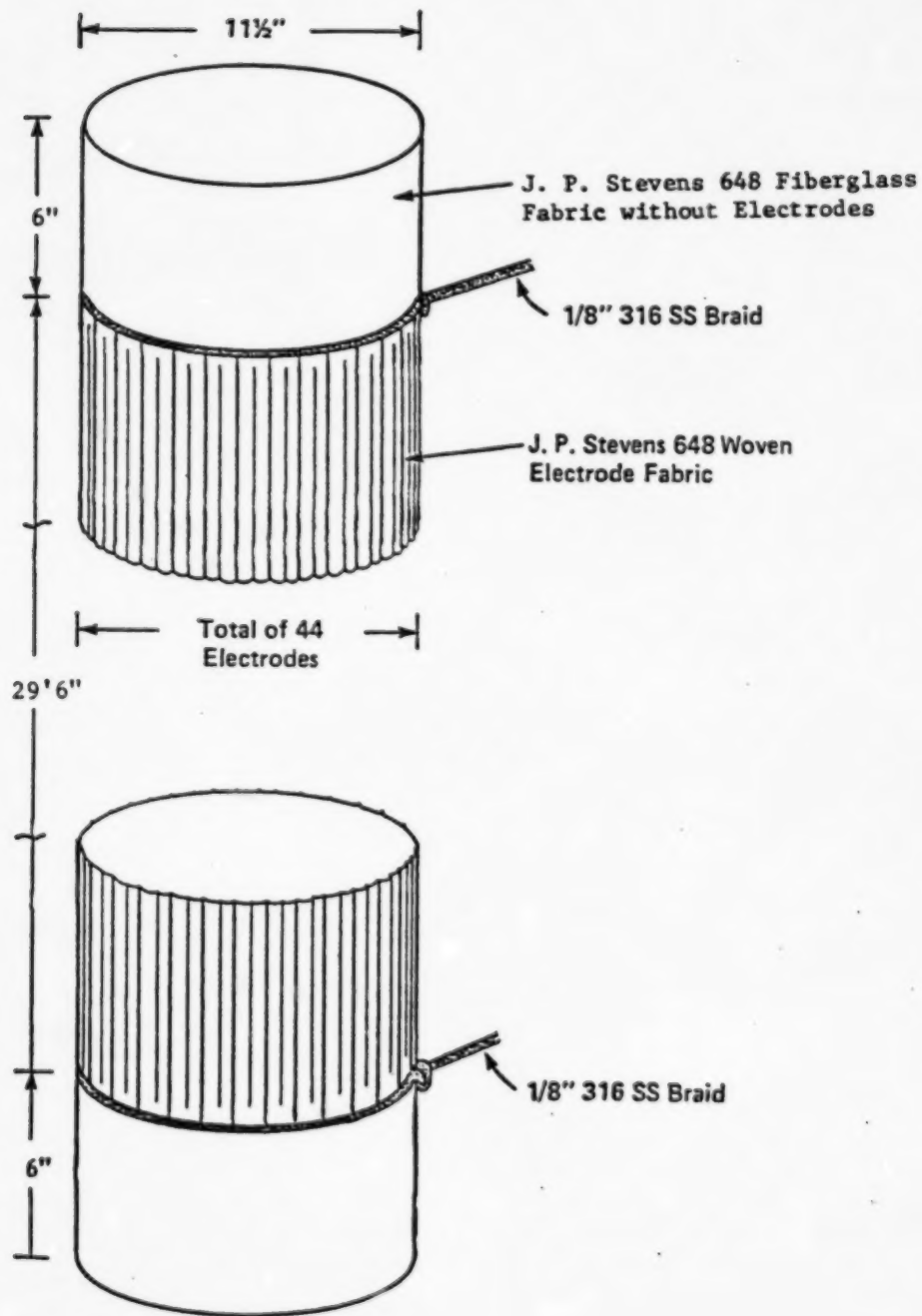
Another type of defect was caused by individual filament breakage in the stainless steel yarn as it traveled from the creel to the loom. Periodically a group of these broken filaments would end up in the fabric. Since each of these defects would cause an electrical short circuit in the finished filter bag, they were also repaired manually on a grading frame at the weaver's plant before shipment to the bag fabricator.

As experience was gained with this fabric, the weaver was able to make adjustments in the loom operation on line, reducing the number of fabric defects. Despite these weaving problems, the feasibility of making this fabric was demonstrated and it was felt that further improvements could be made which would minimize weaving problems.

The fabric was made into filter bags by Menardi-Southern Corporation in Torrance, California. Sixteen bags were constructed as shown in Figure IV. The purpose of the attached cuff was to ensure that there was no electrical contact between the woven electrodes and the metallic thimbles to which the bag is attached.

Two types of anticollapse rings were used with five rings installed in each bag. Solid Teflon O-rings (11-1/2 in. I.D. x 12-1/2 in. O.D.) were used on six bags and conventional 3/16-in. steel anticollapse rings covered with two envelopes of 30-mil Teflon were used on the remaining bags. Solid Teflon O-rings were used to ensure that there was no possibility of electrical contact between alternate woven electrodes through the anticollapse rings. Because these solid Teflon rings were quite expensive, conventional rings covered with a nonconductive Teflon envelope were tested as an alternative. The result after several months' operation was that the Teflon-covered steel rings proved to be more satisfactory than the solid Teflon rings and were also less expensive.

FIGURE IV
ELECTRODE CONNECTION PATTERN



As shown in Figure IV, a 1/8-in. stainless steel braid was connected to every other electrode. By connecting every other electrode to the braid at one end of the bag and the remaining electrodes to a braid at the opposite end of the bag, an alternating plus-minus pattern of electrode polarity was established around the circumference of the bag. Electrical connections were made by attaching the 1/8-in. stainless steel braid, sewn around the circumference of the bag at each end, to leads from the power supply. Connection of the braid to the high voltage system was made inside the baghouse compartment.

Each of the 16 bags was electrically tested at room condition at RTI prior to their installation at SPS. These tests were done with the same type of power supply used at SPS. Twelve of the 16 bags tested passed the test requirement which was a 4.6 mA current flow at -7.0 kV potential. Most of the bags required some manual repair to meet the test. Four of the ESFF bags failed the electrostatic test because of uncorrectable short circuits.

THE ESFF POWER SUPPLY

The system consists of two identical power supplies, each rated at -15 kV, 10 mA. Each power supply was attached to three ESFF bags. The electrical control and monitoring systems included:

- . Continuous digital display and strip chart recording of the applied voltage and current draw for each power supply (i.e., each row of three bags).
- . Continuously variable applied voltage control for each power supply (i.e., each bags).
- . The capability to measure independently, with a panel-mounted analog electrometer, the voltage applied to either row of bags.

In the design and installation of the electrical system, a great deal of care was taken to ensure that the unit was made safe for operating and maintenance personnel. Numerous electrical safety features were incorporated including:

- . All high voltage is removed when the baghouse access door is opened.
- . All high voltage is removed when the power supply cabinet door is opened.
- . All high voltage leads are short-circuited to ground whenever the high voltage is turned off (as it is, for example, in the two cases immediately above) to discharge any static voltage remaining on the bags or leads.
- . A master key is needed to turn the power on at any time and must be in place while the unit is operating. This allows anyone doing maintenance on the unit to remove the key to prevent inadvertent powering of the bags.

An important consideration in the design of the electrical system was the manner in which the power to the bags was controlled during cleaning and filtering cycles. The following features were built in:

- . A 3- to 30-second delay between the time gas flow is returned to the bags after cleaning and the time the electrical power is applied to the bags. This delay allows the bags to become mechanically stable after the filtering cycle begins and is designed to prevent arcing between adjacent bags, which may occur if the bags are moving.
- . Provision to turn the power off as soon as a cleaning cycle is begun. This feature is designed to prevent any arcing that may occur when the bag is cleaned.

OPERATIONAL TEST PLAN

The test plan was envisioned to encompass six phases including the start-up and shakedown period. After completing the shakedown testing, data collection would occur in a series of five test phases. ESFF field strength would be held constant at a value determined in the shakedown tests, and the cleaning cycle as determined in shakedown would also not be varied. These phases were structured as follows:

- PHASE I: RUN THREE DIFFERENT AIR-TO-CLOTH RATIOS USING A FIXED CLEANING CYCLE IN A SERIES OF CONSECUTIVE RUNS OF AT LEAST 2 WEEKS DURATION.
- PHASE II: RUN THE PHASE I AIR-TO-CLOTH RATIOS IN CYCLE MODE IN WHICH THE AIR-TO-CLOTH RATIO IS CHANGED ON A FIXED SCHEDULE OVER A 24-HOUR PERIOD.
- PHASE III: REPEAT OPERATION AT 1 AIR-TO-CLOTH RATIO FROM PHASE I TESTING.
- PHASE IV: REPEAT PHASE II.
- PHASE V: RESERVED FOR TESTING AS SUGGESTED BY COMPLETION OF PHASES I TO IV.

The ESFF pilot unit was started on May 12, 1983, to test instrumentation, the ESFF system, and the mechanical operation of the baghouse. Beginning June 7, 1983, data were taken and the operating limits were explored to set parameters for use in the test plan. The following parameters were determined:

AIR-TO-CLOTH RATIO: The pilot unit could be operated at air-to-cloth ratios of 2.0, 3.0, and 3.4:1. Operation at 4.0 would be possible with the removal of one bag.

ESFF FIELD STRENGTH: The goal of achieving 3 kV/cm was not feasible but 2 kV/cm could be obtained. A transitional effect was observed to occur as a cleaned bag was restarted with steady state developing over time.

CLEANING CYCLE: First settle: 30 seconds
Reverse air: 45 seconds
Second settle: 30 seconds
Reverse gas flow: 1.0 to 1.5 air-to-cloth ratio
Filtration interval: 60 minutes

INLET TEMPERATURE: 400°F

TEST RESULTS

Phase I testing began on June 11, 1983, and was concluded on September 5, 1983. For the lower air-to-cloth ratio tests, six bags were used in each compartment; five bags per compartment were used for operation at an air-to-cloth ratio of 4.0. Testing was conducted using a constant air-to-cloth ratio with inlet gas temperatures at 400°F in the following sequence:

<u>AIR-TO-CLOTH RATIO</u>	<u>DURATION, DAYS</u>	<u>DATA, DAYS</u>
3.0	44	39
2.0	14	14
4.0	24	24

The following average pressure drop results were obtained:

TABLE IV

ARITHMETIC AVERAGE OF DAILY AVERAGE
PRESSURE DROP: PHASE I
(in. H₂O)

<u>AIR-TO-CLOTH RATIO</u>	<u>2.0</u>	<u>3.0</u>	<u>4.0</u>
Control (Non-ESFF)	3.32	6.44	9.46
ESFF	1.98	3.52	5.31
Ratio ESFF/Control	0.60	0.55	0.56

The electrostatic potential applied during Phase I was not constant. It was possible to increase the electrostatic potential gradually as bag operating time accumulated. Energy input also decreased with time so that near the end of Phase I the goal of 3 kV/cm potential was nearly achieved. The following pattern was observed over the order of testing.

TABLE V

PHASE I ENERGY INPUT PATTERN

<u>A/C RATIO</u>	<u>BEGINNING</u>		<u>ENDING</u>		<u>AVERAGE</u>	
	<u>W*</u>	<u>kV</u>	<u>W*</u>	<u>kV</u>	<u>W*</u>	<u>kV</u>
3.0	5.44	4.64	7.15	4.88	6.28	4.75
2.0	6.99	5.30	5.30	5.85	2.78	5.58
4.0	2.25	5.64	0.90	5.90	1.76	5.71

* Per bag

Figures V and VI graphically illustrate the kV-mA pattern which was experienced in Phase I. Figure V depicts results for the east row, while Figure VI depicts those for the west row.

Phase II commenced on October 25, 1983, following the annual turnaround of Harrington Unit 2. This phase of testing was concluded on February 20, 1984, after 119 consecutive days of operation. Phase II was intended to explore the cyclic load effect on pressure drop characteristics which conventional utility baghouses experience; this condition applied to both the control and ESFF bags. The air-to-cloth ratio was changed every 8 hours during an operating day and the following sequence was observed:

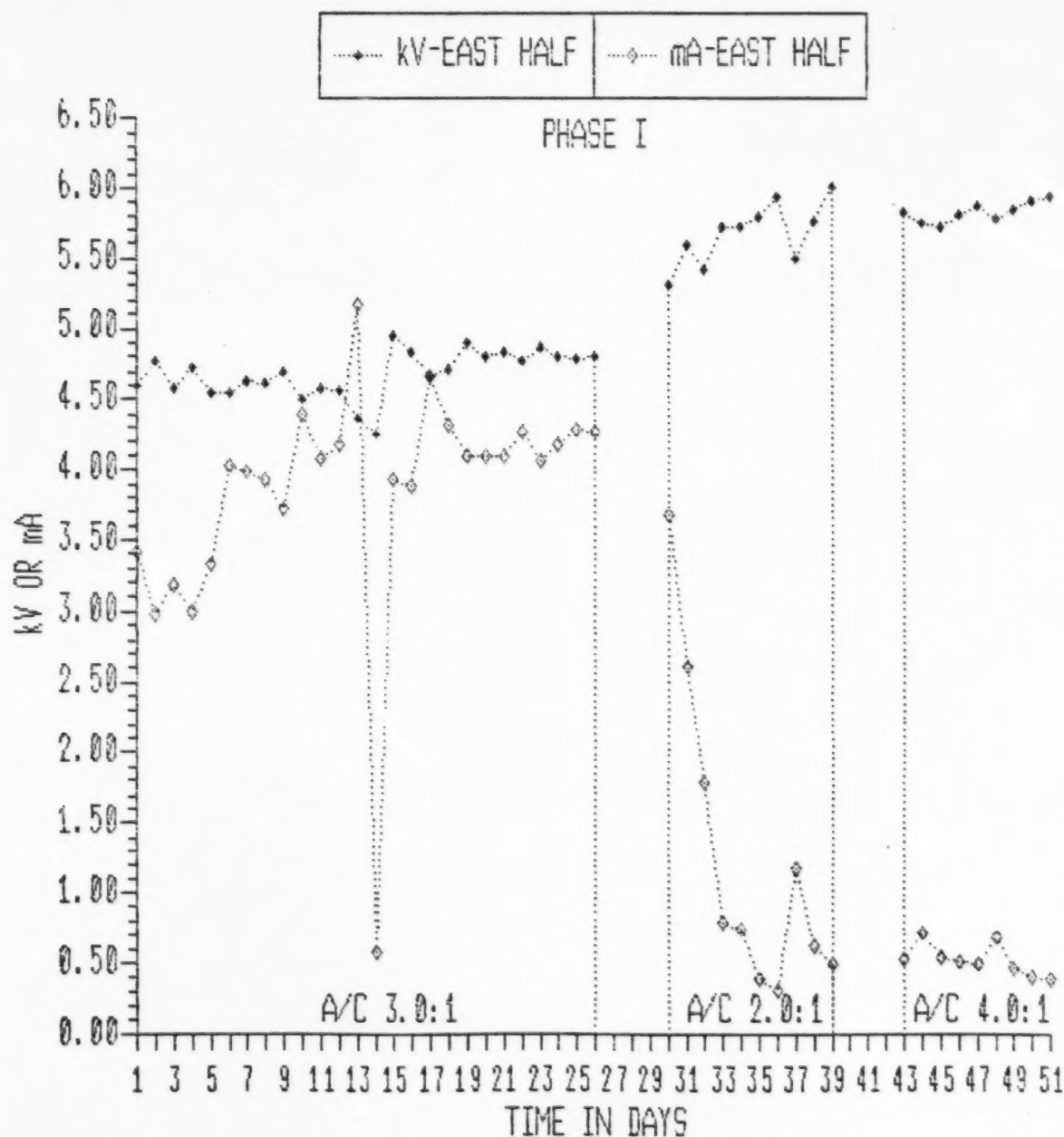
<u>TIME PERIOD</u>	<u>AIR-TO-CLOTH RATIO</u>	<u>FLOWRATE, ACFM</u>
12:00 mn to 8:00 a.m.	2.0:1	915
8:00 a.m. to 4:00 p.m.	3.0:1	1373
4:00 p.m. to 12:00 mn	4.0:1	1830

As before, testing was conducted with flue gas inlet at 400°F and with a 6 kV potential on the ESFF bags.

Table VI shows the average pressure drop data obtained.

FIGURE V

PILOT BAGHOUSE-ESFF kV OR mA vs TIME
06-11-83 thru 09-05-83



Reproduced from
best available copy.



FIGURE VI

PILOT BAGHOUSE-ESFF kV OR mA vs TIME
06-11-83 thru 09-05-83

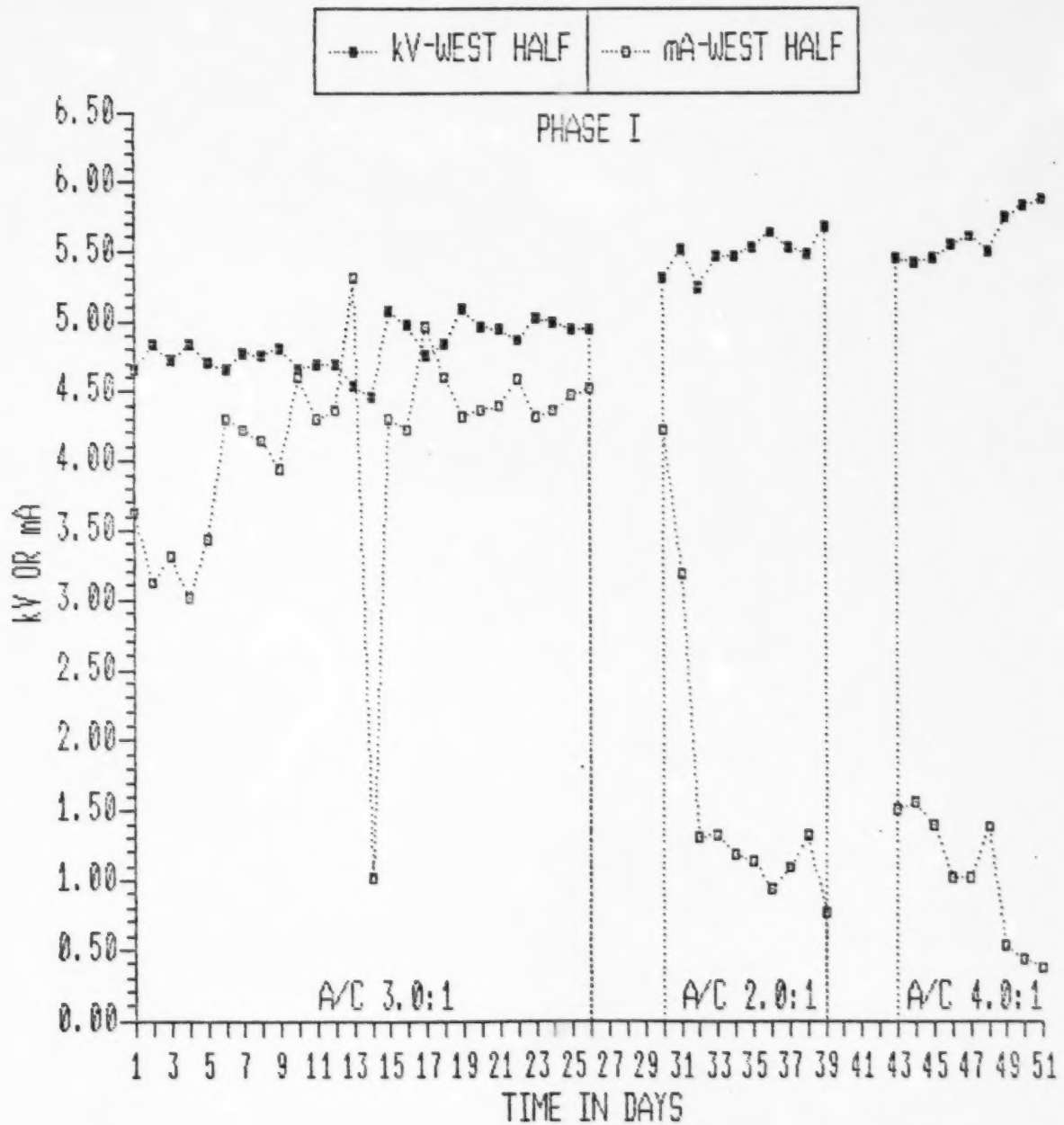


TABLE VI
ARITHMETIC AVERAGE OF DAILY AVERAGE
PRESSURE DROP: PHASE II
(in. H₂O)

<u>AIR-TO-CLOTH RATIO</u>	<u>2.0</u>	<u>3.0</u>	<u>4.0</u>
Control (Non-ESFF)	2.41	5.80	9.55
ESFF	1.58	3.44	5.77
Ratio ESFF/Control	0.66	0.59	0.60

On the average, the ESFF bags exhibited about 62 percent of the pressure drop of the control bags; this compares well with the 57 percent average of the Phase I test. During Phase II testing, the average current flow to an ESFF bag was 0.062 mA for an average power consumption of 0.376 W.

In comparing the constant load operation (Phase I) with the cyclic testing (Phase II) results, the major effect observed occurred at the lower air-to-cloth ratios, particularly at 2.0. Here, average pressure drop for both conventional and ESFF operation in the cyclic mode ranged from 70 to 80 percent of that for the constant load test. The ratio of Phase II pressure drop to that for Phase I at constant air-to-cloth ratio increased to slightly over 1 as the air-to-cloth ratio increased to 4.0. No obvious explanation for these results could be developed from data taken during testing.

The original test plan was modified slightly for Phase III operation in that the inlet gas temperature was lowered to 310°F (target was 300°F) while maintaining a constant load air-to-cloth ratio of 4.0. Under these conditions, the total gas and particulate mass flow rate was increased by about 12 percent over the Phase I flow. Gas phase viscosity was reduced by an estimated 8 percent by the change in temperature.

Phase III data collection began on March 3, 1984, and continued for 17 consecutive days. Table VII compares Phase I and Phase III data, showing that little to no temperature effect is exhibited by the average pressure drop.

TABLE VII
COMPARISON OF AVERAGE PRESSURE DROP DATA
FROM PHASE I AND PHASE III TESTING
(In. H₂O)

	<u>Phase I</u>	<u>Phase III</u>	<u>Difference</u>	<u>Percent Increase</u>
Control P	9.46	9.70	0.24	2.54
ESFF P	5.31	5.41	0.10	1.88
Avg. Temperature, °F	400	310	90	
Test Period, days	24	17		

During Phase III, current flow to an individual ESFF bag increased slightly to 0.074 mA for an average power consumption of 0.447 W.

Phase IV was designed to repeat Phase II test conditions, and the plan was to begin Phase IV testing immediately following the conclusion of Phase III. However, when the inlet gas temperature was raised to 400°F from the Phase III value of 310°F, a 4.0:1 air-to-cloth ratio could not be maintained over a filtration cycle with the conventional bags. Considerable time and effort were expended in attempts to identify the cause or causes of the flow problem. The entire system was inspected for line blockages, faulty dampers, and other mechanical failures; the induced draft fan was checked for both mechanical and electrical performance, and the venturis were removed and inspected. There were no detectable changes in either main unit operation or coal supply. By process of elimination, it was concluded that both the conventional and ESFF bags had experienced a permanent increase in resistance to flow over time. Further examination of the flow recordings indicated that flow control for the conventional bags had actually become marginal near the

end of Phase II testing (400°F inlet operation). However, the ESFF bags because of their better cleaning and filtration characteristics were still capable of operation at an air-to-cloth ratio of 4.0.

Thus, Phase IV operating conditions were modified so that the conventional (control) compartment would be operated at constant load conditions with an air-to-cloth ratio of 2.0 and the ESFF compartment would be operated in cyclic mode using Phase II flow rates. Phase IV commenced officially on August 8, 1984, and was run for 44 consecutive days. The arithmetic mean of the average daily pressure drop data is summarized in Table VIII.

TABLE VIII
ARITHMETIC MEAN OF AVERAGE DAILY
PRESSURE DROP: PHASE IV
(In. H₂O)

<u>AIR-TO-CLOTH RATIO</u>	<u>PRESSURE DROP CONTROL</u>	<u>ESFF</u>	<u>DIFFER- ENCE</u>	<u>ESFF AS A PERCENTAGE OF CONTROL</u>
2.0	4.82	1.97	2.85	40.9
3.0	N/A	4.64	N/A	N/A
4.0	N/A	7.68	N/A	N/A

Average current flow per ESFF bag in Phase IV testing increased slightly to 0.089 mA; average power consumption also increased to 0.553 W.

Phase IV testing was concluded abruptly on September 21, 1984, when the ESFF bags were damaged beyond repair during an unusual main unit boiler upset. The pilot unit had survived main unit upsets before, but in this instance, unlike others, natural gas was co-fired with coal during recovery measures. Possibly, boiler flue gas went fuel rich for a 15 to 20 minute period during the episode when ESFF was activated. Evidence is not conclusive as to whether or not a fuel-rich condition really existed. Boiler

oxygen did go to zero for some period of time when boiler fuel measurements still indicated flow, but no major increase in free carbon content of ash collected in the main baghouse was observed. The main baghouse was by-passed when the boiler firebox pressure exceeded atmospheric early in the event, however, effectively eliminating the baghouse as a source of evidence.

The ESFF bags were damaged by arcing which, by best estimate, commenced some 6 minutes after the initiating event. Unfortunately, no conclusive evidence regarding the conditions which allowed arcing to develop was obtained. Our analysis of the sequence of events indicates that some level of natural gas firing was underway (thus raising flue gas water content) and that the main baghouse by-pass dampers had opened because of positive boiler firebox pressure. Thus, the flue gas was conceivably both higher in water content than normal and probably fuel-rich at the time arcing started.

It must also be noted that the pilot unit was operated some 42 minutes during the episode before gas flow to the fabric filter was stopped and ESFF was turned off. The pilot unit was restarted after the main unit was recovered. ESFF was activated for some 4 hours after restart and exhibited unsteady electrostatic conditions which were presumed to be caused by residual moisture. Thinking this to be a temporary condition, ESFF was maintained. In retrospect, active arcing occurred in the fabric filter for the entire period of ESFF activation before being observed visibly and the unit was shut down.

Inspection the next day revealed that a multiplicity of holes had been burned in each ESFF bag. The holes varied in size and were both localized around an individual wire and developed from wire to wire. The bag inspection report indicated that nodules were formed inside the bags coincident

with many of the burned areas. Some wires had burned in two as well. Circumferentially, holes were found in a random pattern; axially, however, there appeared to be more holes developed near the base of the bag than near the top.

CONCLUSIONS

The ESFF testing which was conducted at Harrington successfully demonstrated the concept of applying electrostatic enhancement to a fabric filter system on a fully commercial scale. The favorable effect of reducing filtration pressure drop observed both in the laboratory and in small scale testing was confirmed. The woven-in electrode concept was successfully demonstrated first in bag construction using conventional weaving techniques and second in operation at commercial scale. No extraordinary maintenance and repair procedures were necessary to sustain operation.

The use of ESFF in conjunction with reverse air cleaning has allowed reverse air baghouse performance (in terms of pressure drop) to approach and exceed that of Harrington's shake/deflate baghouses. Harrington has two baghouses which operate at air-to-cloth ratios of 3.4 and 3.0 (net basis), respectively, during peak loads. In 1984, the average full load pressure differential for the 3.4 air-to-cloth ratio baghouse was 8.8 in. H₂O with bags averaging 41 months of service. In comparison, the phase IV ESFF differential at a 4.0 air-to-cloth ratio was 7.7 in. H₂O or about 12 percent less than the shaker baghouse.

There are, of course, areas which this project has not explored. The effect which different ashes may have on the ESFF process was not evaluated in the Harrington tests. ESFF bag life in the reverse air mode has not been determined nor has the long term pressure differential characteristic of the

ESFF bag been adequately determined. Any differences in particulate capture between ESFF and non-ESFF operation were not measured.

One side benefit of this work is the apparently favorable performance characteristic of the base JPS-648 fabric itself without ESFF. This observation, while not the subject of these tests, suggests that further investigation might be worthwhile.

The most pressing area requiring further investigation is the development of an understanding of the conditions which led to bag failure and the means by which ESFF performance could be restored. Obviously, an enhanced bag protection scheme would be required for any commercial installation. The ESFF concept could also benefit from the development of a more electrostatically resilient bag design suited for use in either reverse-air or shake/deflate systems.

METRIC EQUIVALENTS

Readers more familiar with metric units may use the following to convert to that system.

Nonmetric	Times	Yields Metric
acfm	4.719×10^{-4}	am^3/s
Btu/lb	2.32×10^3	J/kg
ft	0.3048	m
$^{\circ}\text{F}$	$(^{\circ}\text{F}-32)(1.8)$	$^{\circ}\text{C}$
gr/acf	2.29	g/m^3
in.	2.54	cm
in. H_2O	249	Pa
$\frac{\text{in. H}_2\text{O-ft-min}}{\text{lb}}$	1.000×10^4	$\frac{\text{Pa -m -s}}{\text{Kg}}$
$\frac{\text{in. H}_2\text{O-min}}{\text{ft}^2}$	1.61×10^5	$\frac{\text{Pa -s}}{\text{m}^2}$
lb	0.454	kg
lb/MMBtu	430	ng/J
psia	6.89×10^3	Pa
$\mu\text{a}/\text{ft}^2$	10.76	$\mu\text{a}/\text{m}^2$

REFERENCES

- Lamb, G.E.R., and Costanza, P.A. 1977. Electrical Stimulation of Fabric Filtration. Textile Res. J., 47, May, pp. 372-80.